DIAGENESIS OF THE JAISALMER LIMESTONE (JURASSIC), WESTERN RAJASTHAN

DISSERTATION
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BY

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This is to certify that this dissertation "Diagenesis of the Jaisalmer Limestone (Jurassic), Western Rajasthan" is the original work of Mr. Ishteyaque Ahmad. The work on dissertation was carried out at this Department under my supervision.

The dissertation is suitable for the award of Master of Philosophy degree of Aligarh Muslim University, Aligarh.

(**KHURSHEED AKHTAR**)
M.Sc. (Luck), Ph.D. (AMU)

Dedicated To

My

Beloved

Ammi

Abba

and **Bhai Jan**

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I. Ahmad.

(ISHTEYAQUE AHMAD)

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CHAPTER - I

INTRODUCTION

During the last few decades much work has been done outside India on the diagenetic aspects of carbonate rocks. However, very little attention has been paid to the diagenesis of carbonate rocks in this country. There is no publication on the diagenesis of Jaisalmer Limestone.

Blanford (1877), Oldham (1886a, b: 1888) and La Touche (1902) carried out preliminary geological mapping in Jaisalmer area of western Rajasthan. They established the stratigraphic framework and provided excellent description of lithology and fauna of Mesozoic and Tertiary sediments. Geological Survey of India, and Oil and Natural Gas Commission had carried out detailed geological mapping of the Jaisalmer area during fifties and early sixties (Swaminath _et al_., 1956, 1957, 1959; Narayan and Srivastava, 1960; Narayan _et al_, 1961). The acute shortage of petroleum in India has prompted researchers to search for petroleum and generate data on basin analysis, tectonic setting, surface and subsurface stratigraphy of western Rajasthan in general and Jaisalmer area in particular. Several papers dealing with these aspects have been publised (Ghosh, 1952; Bose, 1956; Siddiqui, 1963; Mathur and Evans, 1964; Narayan, 1964; Poddar, 1964; Rao, 1972, Sastri and Datta, 1972; Das Gupta, 1975;Tikku et al, 1976; Pareek, 1981; Misra, 1981, 1982; Datta, 1983.

GEOLOGICAL SETTING

The Jaisalmer basin, spread over 30,000 sq km in area, is the biggest of several sedimentary basins which comprise the western Rajasthan shelf or Indus shelf occupying an area of 1,20,000 sq km (Fig. 1). The shelf extends westward from the Aravalli range across the northwestern slope of Indian Penisular shield, extending beyond the international border, upto the mobile belt of Indus basin in Pakistan. The present architecture of the shelf is the result of interplay of the various structural trends of the Precambrian Indian Shield and their subsequent reactivation. The Indus Shelf merges in the west with the frontier foredeep folded zone of the Sind-Baluchistan orogenic belt (Sastri and Datta, 1972). Several major northwesterly trending sub-surface basement ridges divide the shelf into different basins, namely the Bikaner-Nagaur basin, Jaisalmer basin, Barmer basin, and Sanchor basin, (Fig. 1). Within the broad structural framework the above mentioned individual

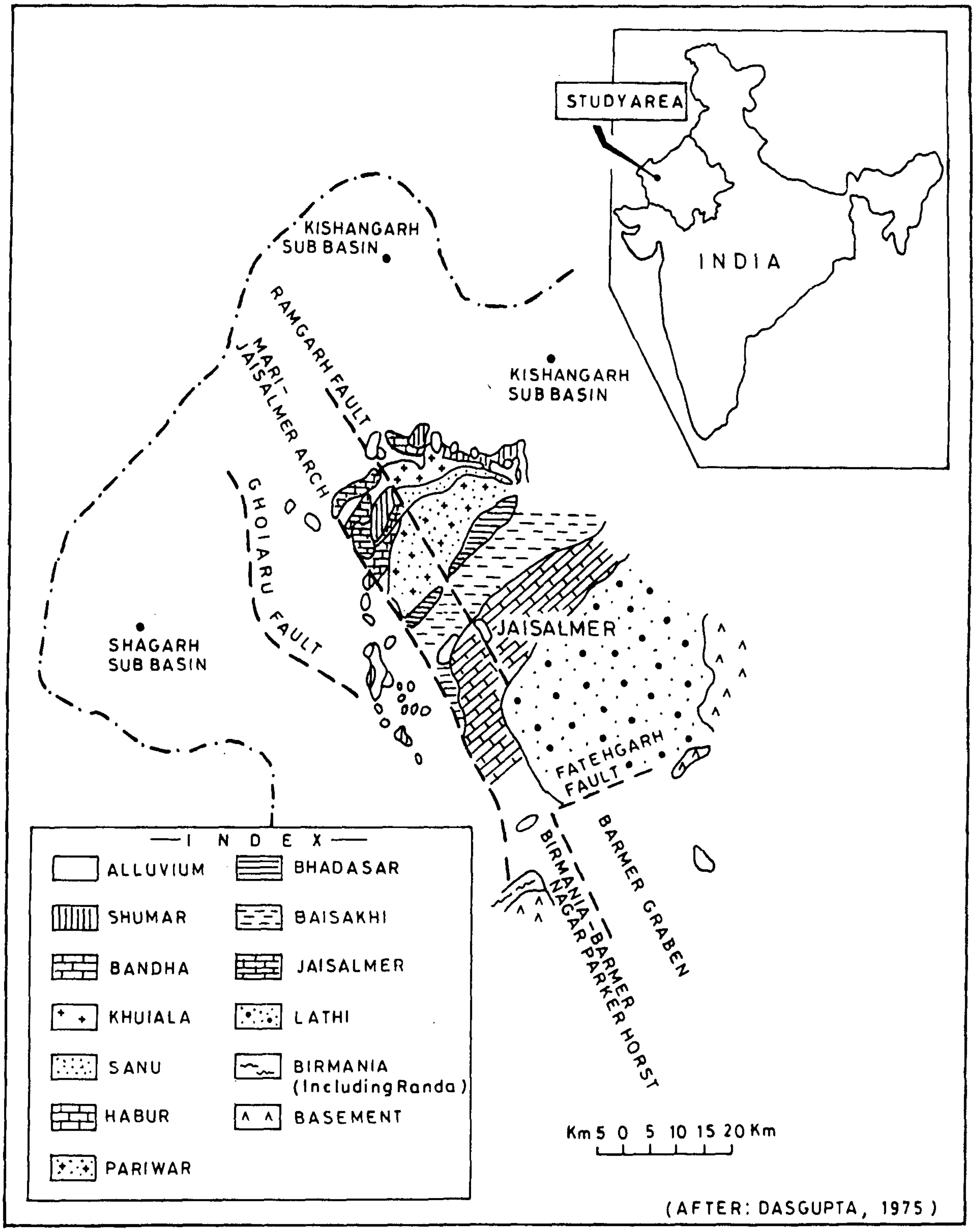

FIG. 1 REGIONAL GEOLOGICAL MAP OF JAISALMER BASIN, WESTERN RAJASTHAN

basins show different trend in their geological evolution.

The geological history of the Jaisalmer basin is akin to that of the Indus shelf and the axial belt, whereas that of other three basins is closely related to the evolution of the western part of the Indian Shield. The Jaisalmer basin is differentiated from north to south into Kishangarh sub-basin, Jaisalmer Mari high, Shahgarh sub-basin and Miajlar sub-basin. Devikot-Pokran Nachna High seperates the Jaisalmer basin from the Bikaner Nagaur basin.

A number of faults trending northwest-southeast, and down faulting of southwestern flank of the Jaisalmer Mari High have been indicated by the geophysical data. It has been noticed that the basement as well as the sedimentary sequence deepen towards southwest with concomitant increase in thicknesses of the various sequences. The Mesozoic sequence is successively down faulted towards south west.

Ghosh (1952) suggested four phases of tectonic evolution in western Rajasthan. The first phase covering the Precambrian-Triassic interval corresponds to the period prior to Indian plate movement. The second phase started from Triassic onwards when the Indian plate broke off from the southern continent and started moving northwards. The collision of the Indian plate with the Asian plate, from Eocene onwards, commenced the third phase resulting in the final phase of regression of the sea during Middle Eocene from the western flank of the Indus Shelf. During the Lower Miocene, the axial belt was completely uplifted and the sea retreated totally from the foredeep and the Indus Shelf. During the fourth phase further uplift of the Sind-Baluchistan fold belt resulted in filling up of the Indus Shelf and the foredeep zone with molasse deposits.

Strong movement along the Murray Fracture zone is evidenced by intense igneous activity in the axial belt and the associated uplift from Jurassic onwards. The pericratonic part of the Indian Shield was simultaneously buckled down and led to the development of the Indus Basin trough. The process was initiated earlier during Triassic (Williams 1959; Sastri and Datta, 1972). With increasing intensity of the movement during Jurassic and Cretaceous, the various pre-existing lineaments within the pericratonic basin were reactivated. The evolution of a differentiated basin architecture was the result of differential movements and adjustments along various pre-existing trends.

SEDIMENTARY CYCLES IN JAISALMER BASIN

Surface as well as sub-surface regional stratigraphy of the Jaisalmer basin has been well established with the help of detailed surface geological mapping carried out by Oil and Natural Gas Commission and Geological Survey of India, and revision of the older ideas on the basis of new data from geophysical surveys, exploratory drilling, and palaeontological and palynological investigations of the outcrop and borehole samples (Narayanan, 1964; Das Gupta, 1975; Datta, 1983).

Several sedimentary cycles have been worked out begining from the Upper Proterozoic sediments to Indus Alluvium of Quaternary age (Table 1).

Proterozoic-Early Palaeozoic sediments deposited in an extensive epicontinental sea in an arid zone, constitute the earlier cycle which terminated with a prominent orogeny and hiatus. During the next sedimentary cycle Periman shallow marine sediments were deposited and the tectonic evolution of the Indus Shelf including the Jaisalmer Basin was initiated. The next phase during Triassic and Early Jurassic was marked by a major regression and deposition of predominantly fluvial to deltaic and epineritic clastic sequence that includes Shumarwali Formation and Lathi Formation.

Table - I Sedimentary cycles in the Jaisalmer Basin (Modified after Datta, 1983).

CYCLE	AGE	FORMATIONS
VII	Quaternary	Shumar Formation
	Kirthar, partly Laki	Bandah Formation
VI	Laki	Khuiala Formation
	Ranikot	Sanu Formation
V	Turonian to Coniacian	Barh Formation
	Albian and older to Cenomanian	Habur Formation/Goru Formation
IV	Neocomian	Pariwar Formation
	Portlandian	Bhadasar Formation
	Kimmeridgian	Baisakhi Formation
	Callovian Oxfordian	Jaisalmer Formation
III	Bathonian to Lias	Lathi Formation
	Triassic	Shumarwali Formation
II	Permian	Karampur Formation
I	Early Cambrian to Proterozoic	Birmania Formation Randa Formation
	Precambrian	Basement.

Subhotina , Datta and Srivastava (1960) have shown that Middle Jurassic carbonate deposition was widespread on an extensive stable shelf. This thick sequence designated Jaisalmer Formation consists of several cycles of carbonate sedimentation, the basal one including considerable clastic influx. During Upper Jurassic stability of the provenance and probably also of the depositional basin was disturbed owing to intense igneous activity in the axial belt. The resulting clastic sequence was deposited in an oscillating shallow marine environment. The Lower Cretaceous (Neocomian) Pariwar Formation represents further regression with shallow marine and brackish water conditions towards the lower part and complete regression with setting in of continental conditions towards the top. During Aptian to Albian, marls and arenaceous limestones of the Habur Formation were deposited in shallow marine environment along the basin margin while further down the basin, Goru Formation represented by marine clastics was deposited. The sedimentation continued during Turonian and ended during Coniacian with the deposition of predominantly marine marl and carbonates with clastic interbeds (William, 1959; Rahman, 1963; Das Gupta, 1975; Sigal & Singh, 1980). The major uplift of the axial belt ended this marine cycle and gave rise to a prominent hiatus ranging in age from Maestrichtian to Danian (Upper Cretaceous to Lower Pleistocene. During Early Paleocene, deposition of clastic sequence of Sanu Formation (Ranikot Formation) took place in brackish to shallow marine environment. Alternating sequence of fine clastics, marls and carbonates were deposited under slightly oscillating condition and the overall transgression continued through late Paleocene and Early Eocene (Sigal et al 1971, Singh 1976). The succeeding Khuiwala formation and Bandah formation of Early to Middle Eocene age indicate somewhat stable condition. The eastern flank of the Indus shelf including the Jaisalmer basin remained uplifted since Middle Eocene. However clastic deposition continued in the deeper basinal part of the shelf. The final phase of uplift of the axial belt started during Oligocene. The intensity of tectonism increased during Middle Miocene and the whole axial belt was uplifted ,attended by complete withdrawal of the sea (Rahman, 1963; Sastri & Datta, 1972). The Indus Shelf continued to subside and molasse sediments of Middle Miocene to Pliocene were deposited while orogenic movements occured in the folded belt area. The quaternary deposits are represented by the Indus alluvium.

AIM AND SCOPE OF THE STUDY

Jaisalmer Basin located on the eastern side of the Indus shelf is regarded as a potential Hydrocarbon basin. Major gas fields of Pakistan are situated in the adjoining western part of the shelf. The stratigraphic sequence from Triassic to Middle Eocene deposited under repetitive, oscillatory transgressive and regressive cycles is considered favourable for development of source, reservoir and cap rocks. Sand dunes/sands of the Thar desert cover the entire Jaisalmer Basin except the eastern and southern parts where outcrop of Phanerozoic rocks overlie the Precambrian basement. The Mesoozoic and Tertiary exposures around Jaisalmer occupy an area of about 7600 sq kms; the Jaisalmer Formation being one of the best exposed Mesozoic formations. The characteristic topographic feature of Jaisalmer Formation are prominent cuestas and extensive dip slopes. The Jaisalmer Formation was deposited on a wide stable shelf with a very low angle depositional slope, thus favouring development of carbonate build-up zone suitable for providing reservoir, cap and source rocks. The area was selected in view of its potential for hydrocarbons.

The present study focuses attention on the textural characteristics and diagenitic aspects of the Jaisalmer Limestone. The study has been carried out on samples collected earlier by the supervisor, Dr. K. Akhtar and his student Dr. Mohammad Aquil. The study is based mainly on thin section petrographic studies. Staining methods were employed for qualitative differentiation of carbonate minerals.

This study is a part of continuing investigations of Mesozoic rocks of western India by Dr. K. Akhtar and his students at the Department of Geology. As a part of these investigations, detailed sedimentological study of the Jaisalmer Limestone, especially carbonate microfacies and environments have been dealt with Akhtar and Aquil (1986). Some aspects of the Jaisalmer Limestone have not been taken up for study so far. One of the aspects is grain size analyses of carbonate grainstones and its relation to depositional environments and compaction history of the sediment. The size, roundness and shape of particles of the Jaisalmer grainstones , especially bioclasts were studied and statistical parameters of grain size were determined.

Another aspect dealt with in this thesis is diagenetic processes that operated to modify the original texture of the sediment. Mechanical compaction were studied with the help of grain to grain contacts and stylolites. The study of cementation included their types, phases and fabrics. Other aspects which were studied included growth of microspar and dolomitization.

CHAPTER - II

TEXTURE OF CARBONATE GRAINSTONES

INTRODUCTION

Grain size analyses serves to describe, classify, and genetically interpret sediments and sedimentary rocks. Initially, grain size analyses were done primarily on siliceous clastic rocks, but in last few years repeated attempts have been made to apply these analyses to carbonates/ sediments and carbonate rocks as well (calcarenites and calcirudites). These grain size analyses should help to provide more information about the depositional environments of carbonates. Grain size distributions are also used to characterize the extent of diagenetic changes in carbonate rocks, because the original lognormal distribution of grain size is changed by cementation, coalescive neomorphism, etc., and secondary bimodal and polymodal grain size distribution may arise (Flugel, 1982).

Carbonate grainstone samples of the Jaisalmer Limestone comprising mainly bioclasts were employed for textural analyses. The textural study included estimation of size, roundness, and shape of bioclasts. Some bioclasts are coated with micrite enveloped. The oolitic coating is generally observed on the echinoderm grains. The oolitic envelope is distinguished from micritic envelop by the concentric nature of the former. A preliminary examination of thin sections showed that in some of them original grain fabric is largely preserved and graiin boundries are clear. In these samples, there is a little modification in texture by compaction and the grains show point contacts to long contacts. These samples were selected for textural studies.

These size of bioclast was measured with the help of micrometer eyepiece, and the well established point counting technique of Chayes (1949) was employed for this purpose. In each section a maximum of 200 bioclasts were measured. The present study employed Ø scale introduced by Krumbein (1934) as this scale facilitates analyses of the size data. Size data was grouped in half Ø class intervals (Appendix 1). The statistical parameters of the grain size distribution were derived with the help of cumulative frequency curves plotted on the basis of grain size data. For plotting the curves grain size in phi unit was represented on the X-axis and cumulative frequency percent on the Y-axis (Fig. 2,3,4). The grain diameters represented by phi 5, phi 16, phi 50, phi 75, phi 84 and phi 95 percentiles were accurately read from the size frequency curves (Table 2). For the studied

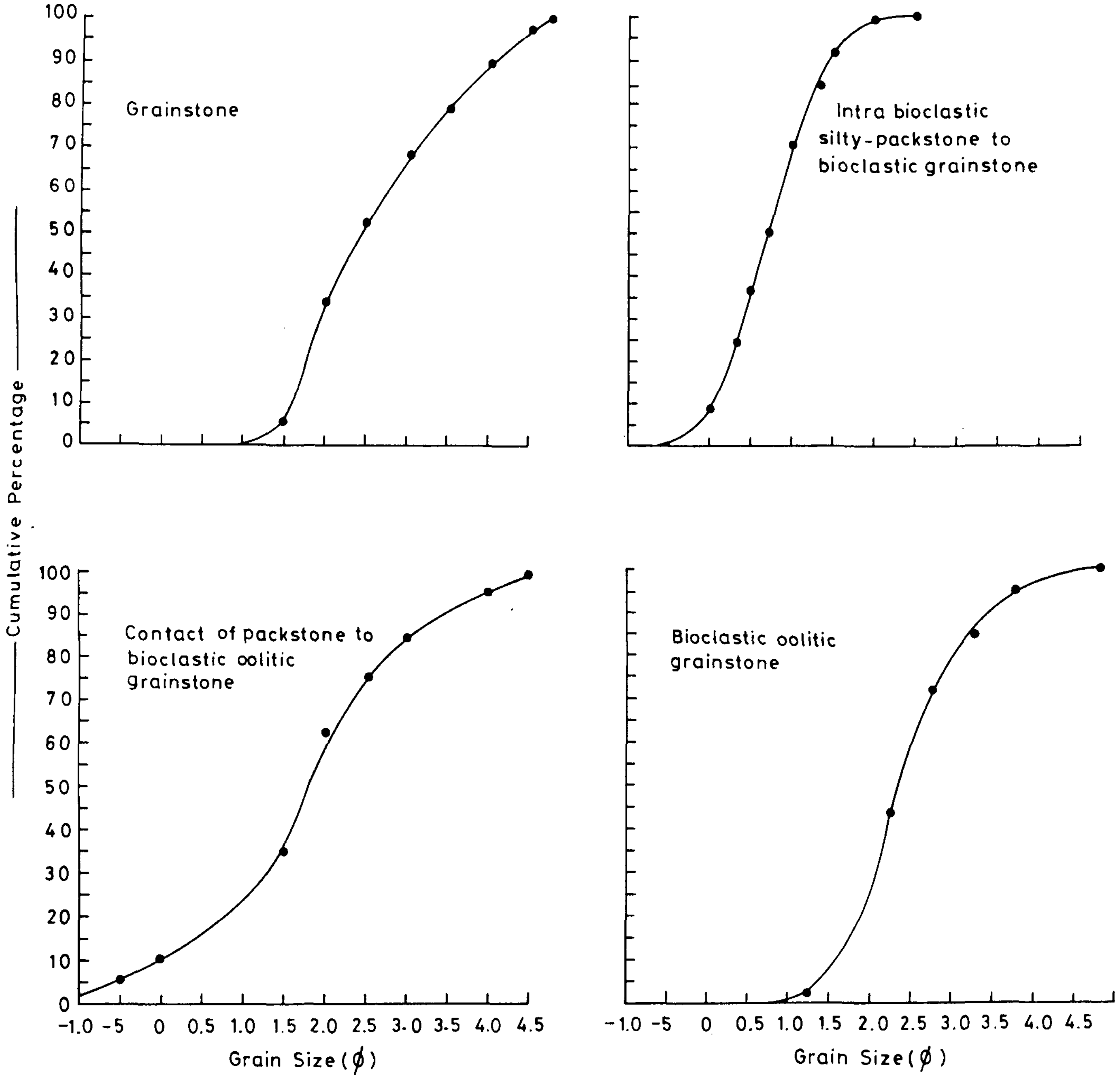

FIG. 2 CUMULATIVE FREQUENCY CURVES OF GRAIN SIZE DISTRIBUTION IN GRAINSTONE(S_{17},S_{28},S_{29},S_{30})

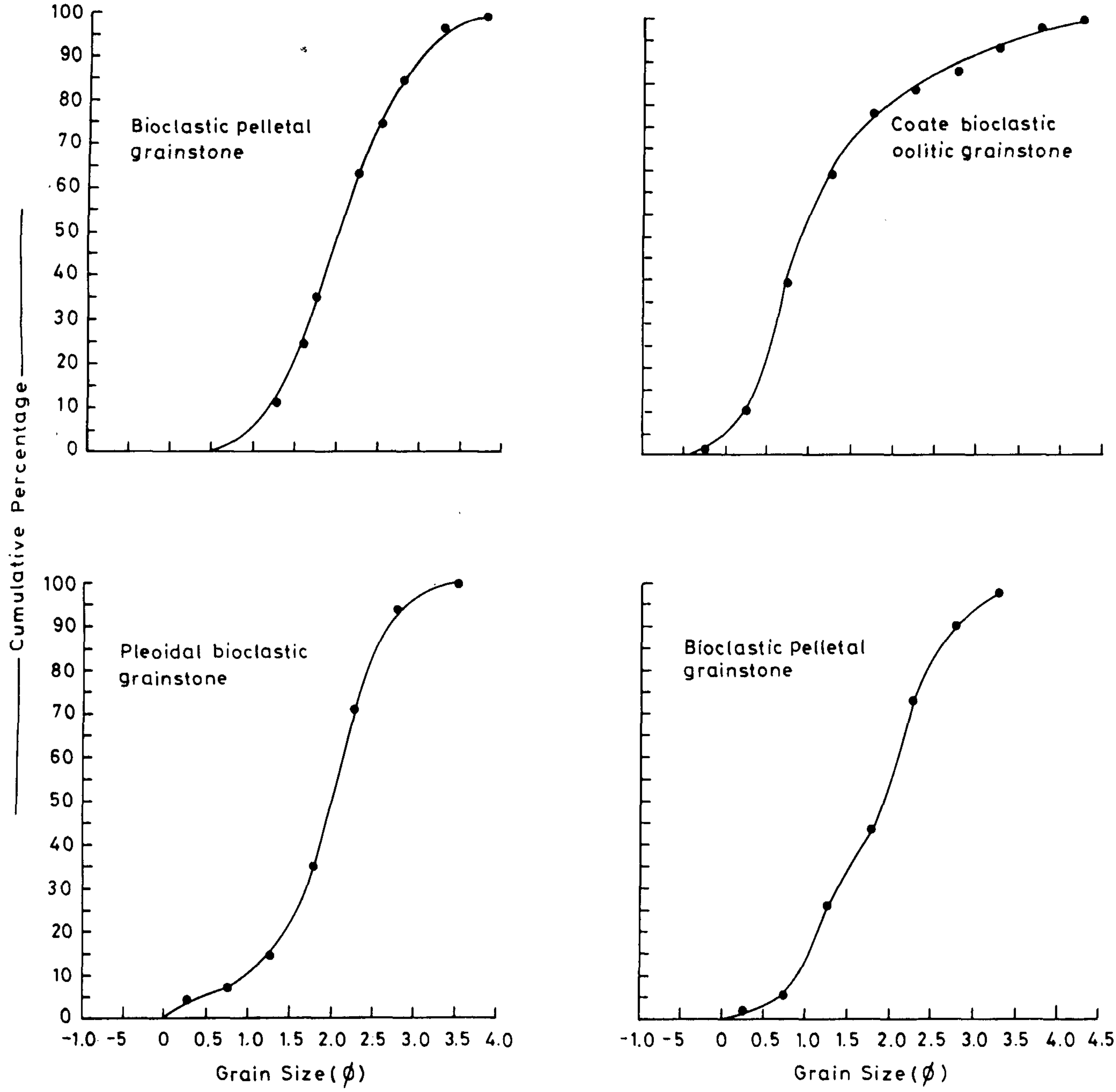

FIG. 3 CUMULATIVE FREQUENCY CURVES OF GRAIN SIZE DISTRIBUTION IN GRAINSTONE (S_{32}, S_{34}, S_{35}, S_{36})

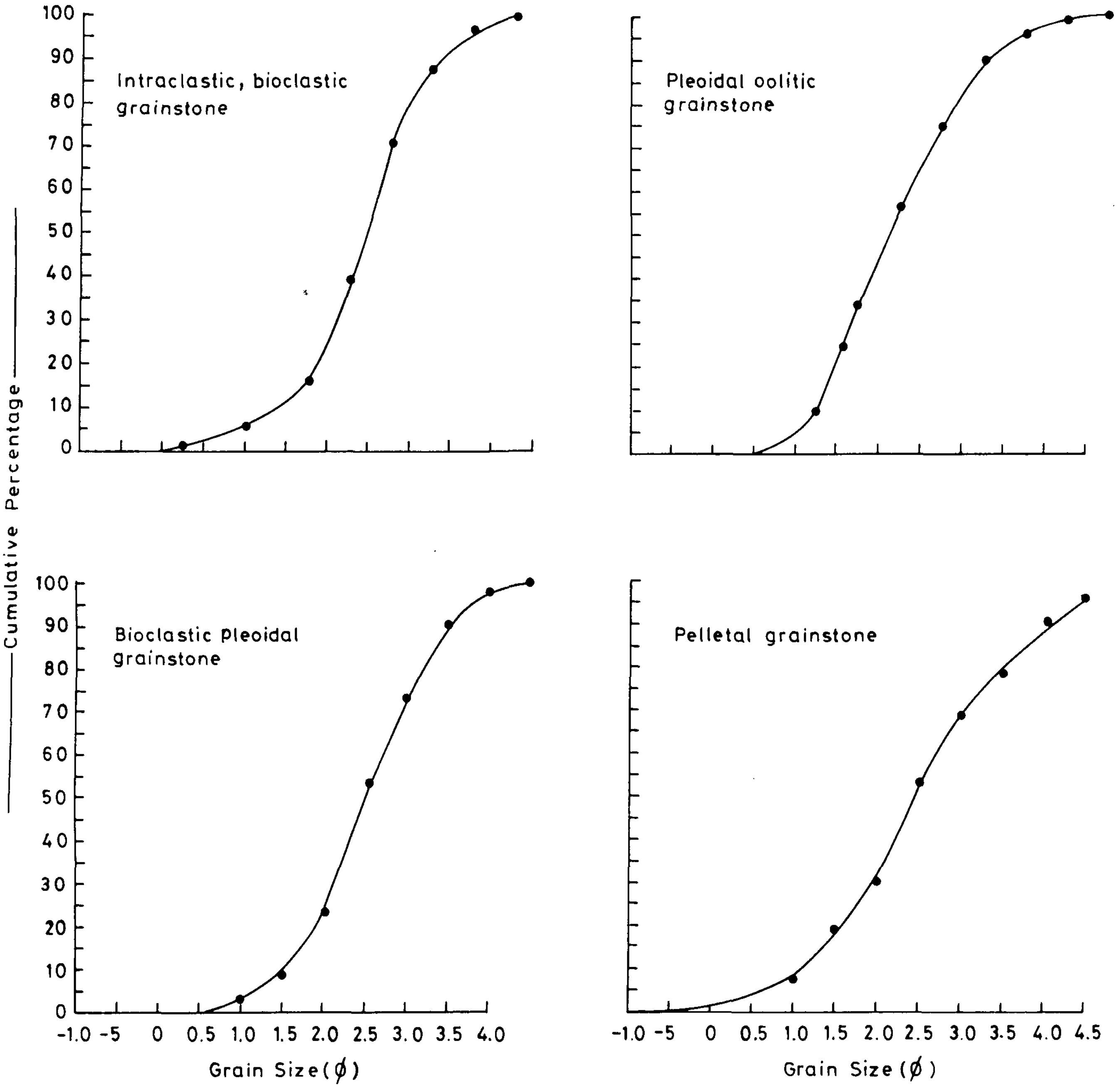

FIG. 4 CUMULATIVE FREQUENCY CURVES OF GRAIN SIZE DISTRIBUTION IN GRAINSTONE (S_{37}, S_{38}, S_{39}, S_{40})

Table 2: Statistical parameters of grain size (percentiles) of Jaisalmer Limestone (grainstones), western Rajasthan, India.

Sample No.	ø5	ø16	ø25	ø50	ø75	ø84	ø95
40	0.5	1.3	1.7	2.5	3.7	3.8	4.5
39	1.2	1.8	2.0	2.5	3.1	3.4	3.8
38	0.8	1.3	1.6	2.0	2.5	3.0	3.4
37	1.0	1.7	2.1	2.5	2.9	3.0	3.5
36	0.4	0.8	1.3	1.8	2.4	2.5	3.2
35	0.3	1.3	1.6	2.1	2.3	2.6	2.7
34	0.1	0.3	0.6	0.9	1.7	2.3	3.5
32	0.8	1.4	1.7	2.0	2.5	2.7	3.2
30	-1.4	-1.6	2.1	2.3	2.7	3.1	3.8
29	-0.5	0.7	1.2	1.8	2.5	3.0	4.0
28	-0.2	0.3	0.4	0.7	1.1	1.3	1.7
17	1.5	1.7	1.9	2.5	3.5	3.8	4.3

limestone samples the statistical parameters of the grain size were calculated with the help of formulae given by Folk (1980). The calculated parameters Include Graphic Mean (M_z), Inclusive Graphic Standard Deviation (σ_I), Inclusive Graphic Skewness (SK_I) and Graphic Kurtosis (K_G). (Table 3)

STATISTICAL PARAMETERS

Folk's (1980) statistical parameters of grain size distribution determined for the Jaisalmer Limestone samples are given in Table 3 and described as follows:

Graphic Mean (M_z) : Graphic Mean was proposed by Folk (1980) as a measure of average size. This parameter of average size is much better than the median because it is based on three points and gives a better overall picture. Graphic Mean (M_z) is much easier to determine as compared to the mean computed by the method of moments. Despite its easy determination, M_z corresponds very closely to the mean computed by the method of moments. M_z is calculated with the help of following formula:

$$M_z = \frac{\phi16 + \phi50 + \phi84}{3}$$

Table 3: Statistical parameters of grain size distribution of Jaisalmer Limestone (grainstones), western Rajasthan, India.

Sample Number	Mz			Verbal limit	SKI	Verbal limit	KG	Verbal limit
17	0.13ø	Coarse sand	0.58ø	Moderately well sorted.	-0.6	Strongly coarse skewed	0.7	Platy kurtic
28	0.10ø	Coarse sand	0.29ø	Very well sorted	+0.13	Fine skewed	0.78	Platy kurtic
29	0.16ø	Coarse sand	0.83ø	Moderately sorted	+0.08	Fine skewed	1.4	Leptokurtic
30	2.33	Fine sand	0.73	Moderately sorted	+0.28	Strongly fine skewed	1.18	Leptokurtic
32	2.03ø	Fine sand	0.74ø	Moderately sorted	+0.09	Fine skewed	1.26	Leptokurtic
34	1.16ø	Fine sand	1.15ø	Poorly sorted	+0.46	Strongly fine skewed	1.30	Leptokurtic
35	2.0ø	Fine sand	0.78ø	Moderately sorted	-0.34	Strongly coarse skewed	0.58	Platy kurtic
36	1.7ø	Medium sand	0.84ø	Moderately sorted	+0.5	Strongly fine skewed	1.07	Mesokurtic
37	2.4ø	Fine sand	0.71	Moderately well sorted.	-0.21	Coarse skewed	1.31	Leptokurtic
38	2.1	Fine sand	1.03	Poorly sorted	+0.16	Strongly fine skewed	1.18	Leptokurtic
39	0.30ø	Coarse sand	0.51ø	Moderately well sorted.	+0.26	Strongly fine skewed	1.2	Leptokurtic
40	2.53ø	Fine sand	1.23ø	Poorly sorted	+0.45	Strongly fine skewed	0.81	Platy kurtic

Graphic Mean (M_z) values of various samples under study range from 0.10 to 2.40∅, i.e. from, coarse sand to fine sand size. In various samples mean grain size is not uniform. The variation in mean grain size suggests that during deposition of the sediment energy conditions were not uniform in the basin.

Inclusive Graphic Standard Deviation (σ_I) : Folk (1980) proposed the parameter "Inclusive Graphic Standard Deviation" as a measure of sorting of the sediments. Sorting is determined by dispersion around central tendency. The tails of a distribution are believed to be environmentally sensitive. Therefore, Folk (1980) designed his measure of sorting in such a way as to reflect the tails of distribution as well. Inclusive Graphic Standard Deviation is calculated with the help of following formula:

$$\sigma_I = \frac{\emptyset 84 - \emptyset 16}{4} + \frac{\emptyset 95 - \emptyset 5}{6.6}$$

The verbal classification scale for sorting proposed by Folk (1980) is as follows:

$\bar{\sigma}_I$			Verbal limit
Under	-	0.35Ø	very well sorted
0.35Ø	-	0.50Ø	well sorted
0.50Ø	-	0.71Ø	Moderately well sorted
0.71Ø	-	1.00Ø	Moderately sorted
1.00Ø	-	2.00Ø	Poorly sorted
2.00Ø	-	4.00Ø	Very poorly sorted
Over	-	4.00Ø	Extremely poorly sorted

Inclusive Graphic Standard Deviation values of the samples under study range from 0.16 to 1.23Ø. Out of 12 samples, 6 samples are moderately sorted, 2 samples are moderately well sorted ,1 sample is very well sorted and 3 samples are poorly sorted. Sorting of the sediments depends upon competency and stability of currents. If currents are of relatively constant strength sediments will be very well sorted to well sorted, but fluctuating currents will give rise to poorer sorting. In most Jaisalmer Limestone samples grains are moderately sorted to moderately well sorted which indicate currents of moderate competency and persistency.

Inclusive Graphic Skewness (SK_I) : It measures the degree of asymmetry of the frequency distribution and is determined by the relative importance of the tails of the distribution. The Skewness or asymmetry is also determined by the position of the mean with respect to median. The skewness is negative, and the sample is coarse skewed when the mean is located towards the coarser side of the median. When the skewness value is positive, the sample is described as fine-skewed because the mean is located towards the finer side of the median. Several formulae for computing skewness have been proposed. However, Inclusive Graphic Skewness is based on the most comprehensive formula as given below:

$$SK_I = \frac{\phi 84 + \phi 16 - 2\phi 50}{2(\phi 84 - \phi 16)} + \frac{\phi 5 + \phi 95 - 2\phi 50}{2(\phi 95 - \phi 5)}$$

Folk (1980) presentd following verbal limits for skewness:

skewness	Verbal limits
+ 1.00 to 0.30	Strongly fine skewed
+ 0.30 to 0.10	Fine skewed
+ 0.10 to -0.10	Near symmetrical
- 0.10 to -0.30	Coarse skewed
- 0.30 to -1.00	Strongly coarse skewed

Inclusive Graphic Skewness (SK_I) values of the samples under study range from -0.6 to 0.50. Out of 12 samples studied ,six samples are strongly fine-skewed, two are fine-skewed and rest are strongly-coarse skewed.

Graphic Kurtosis ((K_G)

Kurtosis reflects the peakedness of the distribution and measures the ratio between sorting in the tails of the curve and sorting in the central portion. If the central portion is better sorted than the tails, the curve is said to be excessively peaked or leptokurtic. When tails are better sorted than the central portion, the curve is deficiently or flat-peaked and platykurtic. The Graphic kurtosis (K_G) is calculated with the help of the following formula:

$$K_G = \frac{\phi 95 - \phi 5}{2.44(\phi 75 - \phi 25)}$$

The following verbal limits for kurtosis were suggested by Folk (1980).

Graphic kurtosis			Verbal limit
Under		0.67	Very platy kurtic
0.67	to	0.90	Platy kurtic
0.90	to	1.11	Mesokurtic
1.11	to	1.50	Leptokurtic
1.50	to	3.00	Very Leptokurtic
Over		3.00	Extremely leptokurtic

Kurtosis values of the studied samples range from 0.58 to 1.4. Out of 12 samples, seven samples are leptokurtic, four samples are platy kurtic and one is mesokurtic.

Several workers have carried out grain size studies on Recent sediments and attempted to discriminate the different depositional environments on the basis of grain size data (Folk and Ward, 1957; Mason and Folk, 1958; Friedman, 1961; Duane, 1964). Application of these studies for recognising depositional environments in ancient sediments only on the basis of grain size parameters is full of discrepancies. However, grain size parameters do reflect the energy conditions within a basin, and this approach was followed in the present study of the Jaisalmer Limestone samples.

The sign of skewness can be related to the environment energy, and therefore to environment (Duane, 1964). Where winnowing is a dominant force, here equated to high-energy, as in the tidal inlets, the littoral zone, and beaches, as well as most of the barrier island, the sediments are very dominantly negatively skewed. Areas where energy levels are low, are characterized by positive skewness.

Most of the studied samples of the Jaisalmer Limestone are positive or fine skewed indicating lack of winnowing action of waves and currents, that is low energy environment and deposition in protected environment or below wave base. Presence of some negatively or coarse skewed samples evidences rarely occurring strong and persistent currents.

ROUNDNESS AND SPHERICITY

Carbonate particles are not directly comparable with siliciclastic grains or pebbles with regard to roundness and shape. The reason for this is that the carbonate particles show wide variation in their ability to resist mechanical and chemical influences and because they possess different initial shapes. Despite these limitations ,observation of roundness and sphericity of transported carbonate particles can be quite helpful because a change in shape and roundness does take place in bioclast and other allochems.

The present study employed the chart of Pilkey et al. (1967) for estimating the roundness of carbonate bioclasts. According to this chart, most bioclasts in the studied samples fall into class 4, being fairly well rounded to very well rounded.

The sphericity of the bioclasts and other allochems in the studied samples was visually estimated with the help of comparision chart devised by Krumbein and Sloss, 1963. The studied allochems show bimodal sphericity as a result of differences in original shape of particles. For example, fragments of brachiopod shells were originally elongated and they still have low sphericity despite becoming well rounded. On the other hand bioclasts having originally eqriedimensional shape as well as peleoids show high sphericity along with well rounded shape.(Fig. 5)

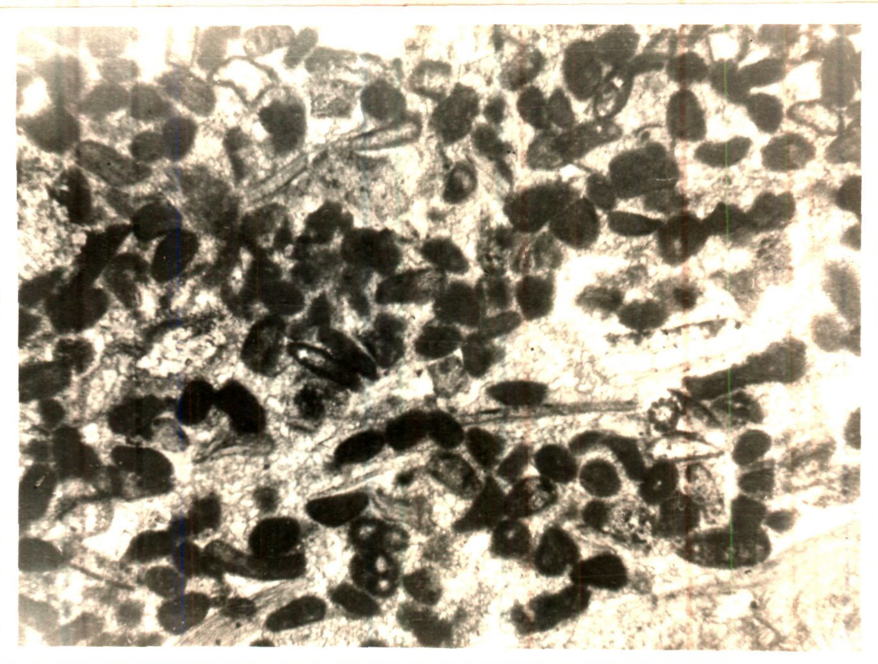

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Figure 5. Pelloidal bioclastic grainstone showing bimodal sphericity with well rounded pelloids of high sphericity and elongated brachiopod fragments.

CHAPTER - III

C O M P A C T I O N

INTRODUCTION

Diagenesis includes cementation and compaction as the two major processes of lithification which take place in a sediment subsequent to deposition and prior to weathering and metamorphism.

Compaction refers to any process that decreases the bulk volume of rocks. It includes mechanical processes that decrease the bulk volume of single grains (grain deformation) or that cause closer packing of grains (re-orientation), and pressure solution which decreases the volumes of grains and of cement materials; (Flugel, 1978). Pressure solution is chemical compaction and increase in grain packing density and also includes formation of stylolites. Stylolites represent pressure solution along seams that are laterally extensive on the scale of hand samples and that cut numerous grains, mud and cement. Pressure solution involves the solubility of elastically strained calcite at grain (cement-crystal) contacts. The strain in turn results from linear stress due to overburden. (De Boer, 1977).

The present study on the compaction of Jaisalmer Limestone has been carried out on skeletal grainstones and skeletal packstones. Many thin sections studied show compaction features. These compaction features reflect both mechanical and chemical processes.

MECHANICAL COMPACTION

Mechanical compaction can be recognized through out the Jaisalmer Limestone. Features indicating mechanical compaction include grain breakage, plastic grain deformation and grain re-orientation (Meyers, 1980). The bulk of mechanical compaction consist of grain deformation of skeletal grains of brachiopod whereas grain deformation of single crystal echinoderm is rare. Mechanical grain deformation is particularly intense in some grain-supported rocks.

Grain breakage was important mechanical compaction process as compared to the plastic deformation and re-orientation of the grains. Certainly there has been grain rotation in fine grained packstones and grain repacking in coarse grained rocks, but there is no clear evidence. Grain breakage includes fragmentation of shells and displaacement of fragments (Fig. 6). Compactional breakage of brachiopod fragments is seen as across shell fracture (Fig. 7). Minor plastic deformation has been observed in few samples which show skeletal fragments bent

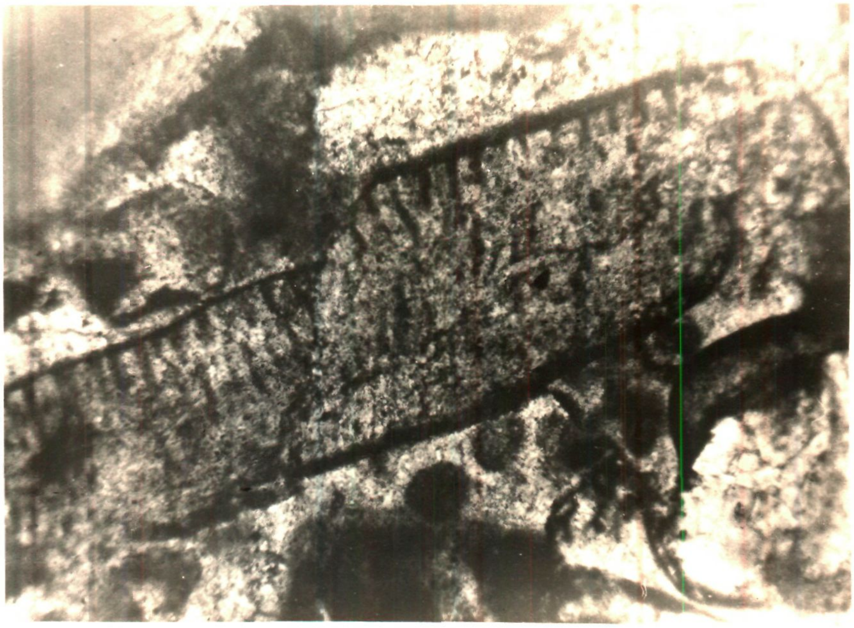

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Figure 6. Breakage of a bioclast showing displacement along the fracture.

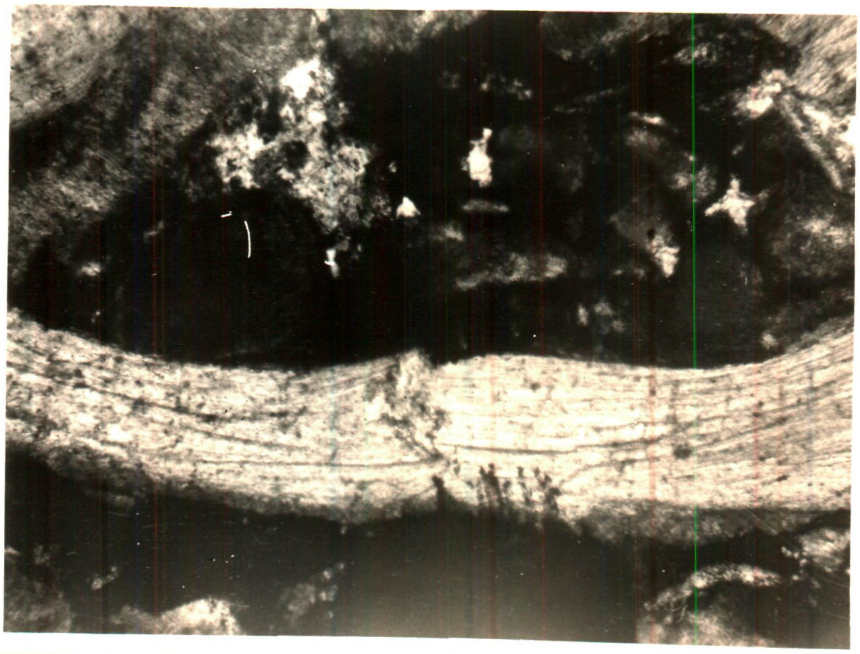

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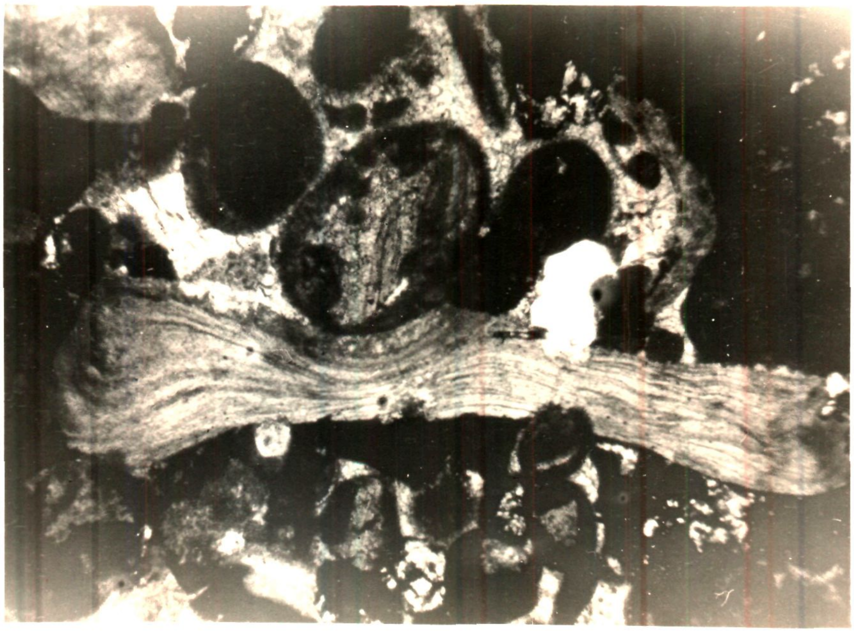
Figure 7. Cross shell fracture in a brachiopod fragment.

against peloid grains (Fig. 8). Mechanical rearrangement of grains probably occurred in some rocks before major grain deformation, as implied by packing densities. Grain rotation almost certainly occured during mechanical compaction, however it is difficult to recognise and evaluate because of general absence of suitable monitoring features of rotation, such as rotated geopetal structures. Minor grain rotation obviously accompanied the shell breakage, which is also accompanied by drag fabrics around large compaction resistant grains (echinoderms) and cement rich patches of echinoderms. These fabrics are most common in fine grained packstones. They comprise the alignment of elongated grains parallel or sub-parallel to the resistant elements and involved both grain rotation and chemical compaction.

Petrographic observations suggest a hierarchy of susceptibility of grains to mechanical compaction. Mechanical compaction occured during cementation of the Jaisalmer packstone and grain stones. Evidence that shell breakage in some rocks occured before cementation is the presence of broken shell fragments encased in cements. Other samples show compaction during cementation as the shells are broken and bent around the cement. Minor intragranular pressure solution, breakage of bioclasts accompanied by minor displacement indicates the post-cement compaction.



X47

Figure 8. Plastic deformation of a bioclast which is bent against a micritized bioclast.

X138

Figure 9. Microsutured boundary between a brachiopod fragment and a pelleoid.

CHEMICAL COMPACTION

The most common chemical compaction feature observed in the Jaisalmer Limestone is pressure solution at grain contents. The bending of brachiopod shells and of the other skeletal fragments by adjacent grains (Fig. 8) indicate that this type of deformation is the result of pressure solution rather than indentation (Deelman, 1975). Had plastic indentation been the dominant process there should be identifiable strain effects such as deformed cleavage in the skeletal shell. Pressure solution between the shell fragments show that the parts of the shell fragments have been dissolved at the contact. Microsutured brachiopod fragments indicate minor dissolution and moderate chemical compaction (Fig.9).

Intergranular pressure solution and intragranular pressure solution occurs in some samples. Intergranular pressure solution occurs between the two adjacent grains, where dissolution at the contacts have taken place (Fig. 10); intragranular pressure solution took place after cementation. Most chemical compaction involves brachiopod and bryozoa grains. In pressure solution contacts between bryozoa and brachiopod, the brachiopods have undergone more dissolution than the bryozoa. Contacts between them are planar to concavo-convex in which little dissolution of

X138

Figure 10. Intergranular pressure solution between a brachiopod fragment and another grain.

X47

Figure 11. Microstylolites rich in ferruginous clay cutting through grains and cements.

the adjacent skeletal grain has taken place. Pressure solution occurs even in slightly compacted grainstone. Age relationship between pressure solution features and cements are often ambiguous. For example, pressure solution between two bioclasts could have occurred before any cementation, the cement being dissolved and lost during pressure solution. Consequently, the amount of pre-cement compaction in any sample can not be adequately evaluated. Only rarely can chemical compaction definitely be identified as pre-dating the first generation of cement. (Meyers, 1980). Chemical compaction after some cementation is relatively common and is identified by pressure solution contacts between a cement crystal and an adjacent grains.

Intragranular compaction, where the pressure solution occured within the skeletal shell, is the indication that cementation occured during compaction. Some other petrographic features indicate chemical compaction occured after cementation. For example, pressure solution contacts between two grains often extend laterally beyond grain boundaries as the minor sutured contact between the two adjacent grains. The cement-grain sutured contacts are continuations of known intergranular pressure solution contacts. Additionally the preferential intergranular chemical compaction on the tops of the bioclast, the pressure solution between brachiopods and cements and the intragranular chemical compaction of bioclasts surrounded by cements are all evidences of compaction after cementation.

Stylolites and drag fabrics are two other chemical compaction phenomena occuring in the studied limestone. But the evidence for the drag fabrics is not clearly available. Stylolites are thin zones of discontinuity within rocks. In thin sections they appear as undulate to zig-zag sutures. In general, they consist of conical to columnar projections with intervening depressions. Stylolites are generally regarded as the result of pressure solution. This involves solution around point of contact between mineral grains in response to pressure. Since certain minerals are more susceptible to pressure solutions than others, various burial depths are necessary in order to produce strong stylolization. In the Jaisalmer Limestone samples, microstylolites are observed which cut through grains as well as cements (Fig. 11). Since they originated mostly after intragranular compaction the stylolites are essentially post cementation.

CHAPTER - IV

C E M E N T A T I O N

INTRODUCTION

Cementation is one of the important aspects of diagenesis of carbonate rocks. A sufficient amount of dissolved carbonates is available for cement formation in shallow marine environments and in zones permeated with fresh water. The present study of cements of Jaisalmer Limestone included recognition of types of cements, phases of cementation and reeconstruction of digenetic environments and facies.

TYPES OF CEMENTS

Three types of calcite cements were recognised in the Jaisalmer Limestone samples which include fibrous cement (2-3%), granular cement (10-15%), and syntaxial rim cement (1-3%) of the total rock volume.

Fibrous Calcite Cement: Fibrous calcite cement forms isopachous crusts, 0.1 mm to 0.4 mm in thickness. The isopachous crusts consists of fibrous crystals and the long axis of the fibrous crystals lie perpendicular to the encrusted grain surface (Fig. 12).

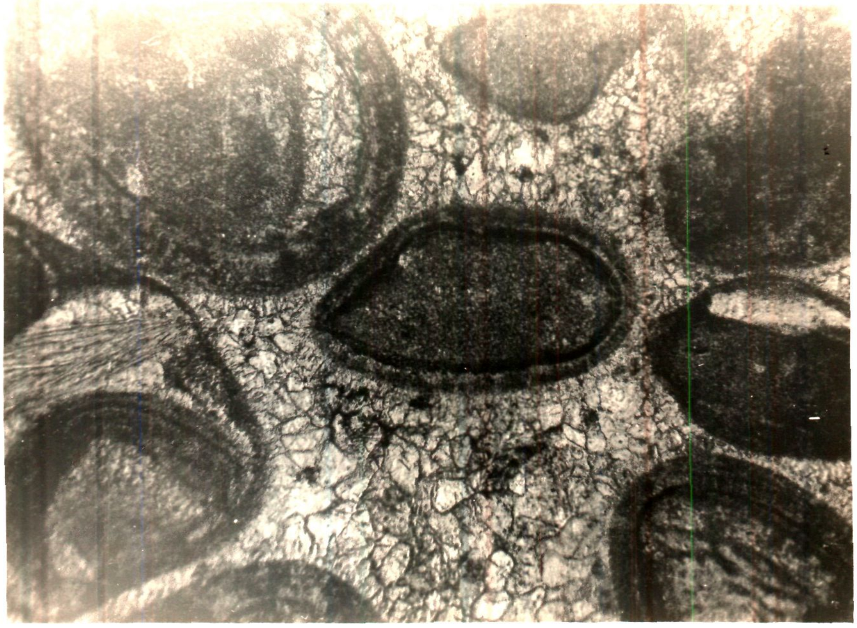


Figure 12. Fibrous calcite cements forming an isopachous crust on a grain.

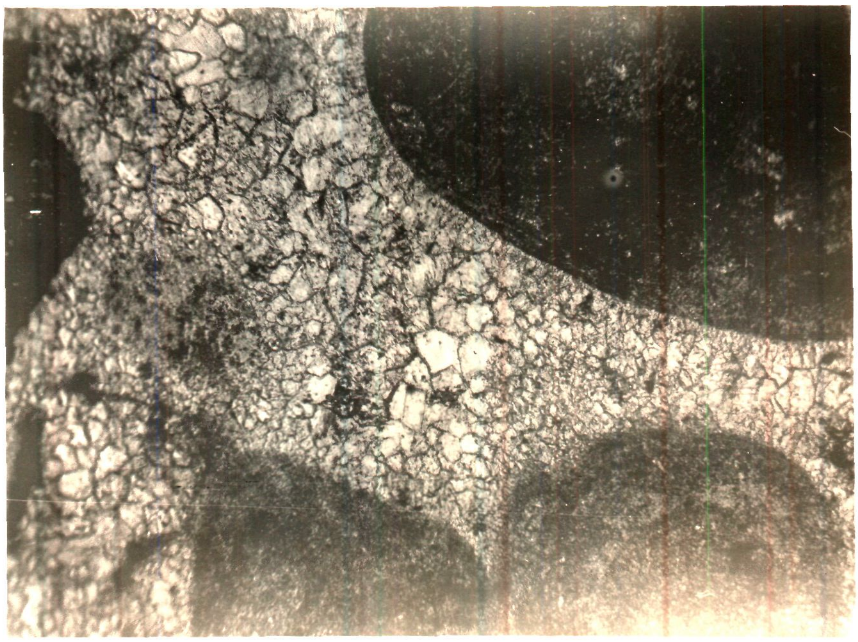


Figure 13. Granular cement occurring as pore filling in the intergranular spaces.

The fibrous calcite is believed to be a very early post-depositional submarine cement which was precipitated while pore waters were still in close communication with normal marine water. The isopachous distribution of the fibrous crust is indicative of a phreatic environment. Bricker (1971) pointed out that all recent submarine and beachrock cements are of bladed and fibrous habit, while most freshwater and subsurface cements are not. Folk (1974) pointed out that the presence of high Mg^{++} Ca^{++} ratio in the normal marine water are responsible for the fibrous calcite cement.

Granular Cement : The granular cement, also designated blocky, equant and drusy cement by some authors, is present in almost all the samples of Jaisalmer Limestone. It seldom comprises more than 10 percent of the total volume of rocks and the maximum amount is 15 percent. The cement is composed of anhederal or subhederal crystals of clear calcite. The cement generally occurs as pore fillings in the intergranular spaces (Fig. 13). Sometimes it occurs as intragranular cements filling up internal cavities of the brachiopod shells. The crystal size ranges from 10 to 30 millimicron in size and the crystal size increases away from the substrate (Fig. 13) and may reach a diameter up to 40 millimicron. The cement crystals have straight or slightly curved crystal interfaces (Fig. 13). The distribution of granular cement is not uniform, but tends to be concentrated at grain contacts and in the smaller pore spaces.

Syntaxial Rim Cement : In the Jaisalmer Limestone, the syntaxial rim cement occurs in smaller proportions comprising 1-3 percent of the total rock volume. The cement growth has taken place on the echinodermal nucleus (Fig. 14). The cement overgrowth is about 50 millimicron thick. The overgrowths show strongly preferred orientation and are in optic continuity with the host echinoderm nucleus. The cements are exclusive to and always syntaxial on echinoderm.

The high degree of substrate selectivity and syntaxial growth on substrate imply that pore waters had low levels of oversaturation with respect to calcite. In some cases, the growth of the syntaxial cements are partial on the echinodermal grains. This partial development of the syntaxial rim cement is due to the coating of the micrite on grains. The coating of the micrite has prevented the further development of the syntaxial cements.

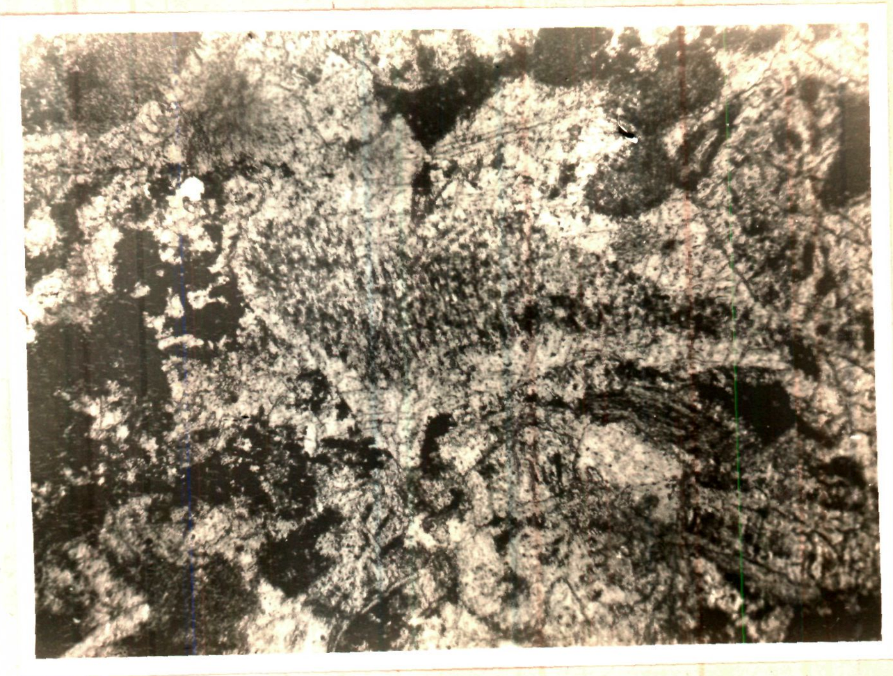


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Figure 14. Syntaxial rim cement occurring as over growth on an echinodermal fragment.

PHASES OF CEMENTATION

The Jaisalmer Limestone samples show mainly two phases of cementation. The two phases are characterised by cements which differ markedly in fabric characteristics. The earlier phase of cementation is represented by fibrous cement (cement A) which grow from the grain surfaces and partly filled up the intergranular pore spaces. In the latter phase, the remaining pore spaces were filled up by a different type of cement (cement B). The two cements are described below:

Cement - A : Fibrous cement forms about 10 percent of the total cements present in a sample. It shows palisade-like overgrowth normal to the particles and grow outward into pore spaces (Fig. 12).

The origin of the fibrous crystal in the Ancient Limestones consider not only replacement of marine acicular aragonite or high-Mg calcite but also void-filling calcite, vadose cements or recrystallized micrite. It is very difficult to relate the replacement fabric to a corresponding precursor minerology and habitat. Most authors presuppose a primary marine aragonite or high Mg calcite minerology. The fibrous cement is common in shallow marine environment. One-third of the studied samples, show the cement A phase.

studies of diagenetic environments in carbonate rocks have been summarised and published by Folk (1973, 1974), Mathews (1974), Bathurst (1976), Friedman and Sanders (1978), Moore (1979), and Longman (1980).

Longman (1980) recognised basically three diagenetic environments which include - marine phreatic environment, fresh water vadose environment, and fresh water phreatic environment.

The presence of isopachous fibrous crust on the grains in the studied samples is considered to be a leading criterion of marine cements. In all probability cementation occured in the active marine phreatic zone, because in the stagnant marine phreatic zone little cementation occurs as a result of water moving too slowly through the sediments. The active marine phreatic zone refers to warm shallow seas where all the pore spaces are filled with normal marine water. The water is forced through sediments by waves, tides or currents. A change from marine phreatic to fresh water phreatic environment brough about precipitation of sparry calcite cement occuring in the form of granular mosaics. The phreatic zone lies between the vadose and the mixed marine, phreatic-fresh water zone. All pore space is filled with meteoric water containing variable amounts of dissolved carbonates. The top of the phreatic zone is marked by the water table, whereas the lower boundry is gradational with marine water in areas proximal to the sea.

The syntaxial overgrowth on echinoderm fragments (syntaxial rim cements) observed in the studied samples are another characterstic feature which indicate a fresh water phreatic environments.

There is a possibility that a regressive phase accompanied by a fall in sea level brought about a change from marine phreatic environment to fresh water phreatic environment which is reflected in the two phases of cementation described elsewhere as cement - A and cement - B.

CHAPTER - V

DOLOMITE AND DOLOMITIZATION

INTRODUCTION

Dolomite may be formed by penecontemporaneous replacement of unconslidated sediment, but more frequently by replacement of pre-existing limestone. Dolomitization is controlled by permeability, composition and particle size of the host rocks, and by physico-chemical parameters including temperature, pressure, and ionic concentration and composition of the pore fluids. Dolomite formed during shallow burial below the sea floor is now recognised as a common component in the Neogene organic rich sediment deposited on continental margins and in small ocean basins (James, 1988; Piscoitton, 1981; Garrison et al, 1984; Baker and Burn, 1985).

Patterns of dolomitization are controlled by microscale and macroscale factors, in turn controlled by permeability. Replacement dolomite commonly shows strong fabric selectivity. Typically fine matrix carbonate is replaced first, followed either by latter clast replacement or vuggy solution porosity enhancement. On a large scale, patterns of dolomitization are controlled by-

1. paleogeographic setting of originally permeable limestone units, relative to a source of dolomitizing pore fluids;

2. exposure at unconformities;

3. paleogeographic distribution relative to tectonic highs or regions of subaerial exposure,

4. timing of eustatic fluctuation controlling movement and evolution of ground water and connate water, and

5. relationship to the paleoground water conduits or water table.

Dolomitization of pre-existing limestone commonly enhances the permeability and improves porosity. Dolomitization may have a homogenizing effect on a carbonate reservoir, so that the permeability within the reservior is improved. Because of its low ductility relative to limestone (and sandstone) the reservior characterstics of dolomite often are enhanced by fracturing (Davies, 1979).

DESCRIPTION OF DOLOMITE IN JAISALMER LIMESTONE

Dolomite in the Jaisalmer Limestone was studied using standard thin section technique. Calcite and dolomite were differentiated by staining method of

Friedman (1967). Dolomite mainly occurs in the lower two members of the Jaisalmer Limestone, i.e. the Hamira Member and the Joyan Member.

Hamira Member comprising mainly terrigenous micrite shows extensive dolomitization and recrystallization. The average composition of the rocks is:dolomite 45 percent, neomorphic spar 22 percent, and terrigenous admixture 25 percent. Several minor constituents comprise remaining 8 percent of the rocks. Dolomite occurs in patches as well as single floating crystals. The dolomitized patches consist of crystals which are highly ferrugenous and show dark margins or appear completely dark (Fig. 15). The dolomite rhombohedera patches are tightly interlocked and mutually interfering (Fig. 16). The single floating crystals of dolomite are very finely crystalline to finely crystalline (Fig. 17). The buff colour and zoning of dolomite crystals is due to increased iron content. Remnant micrite occurs in the centre of some dolomite crystals. Some times dolomites occur as streaks.

Dolomitization has affected mainly pleoids. Some completely dolomitized pleoids still retain a typical pleoidal shape. The dolomite has also replaced intraclasts and bioclasts. In early stges of

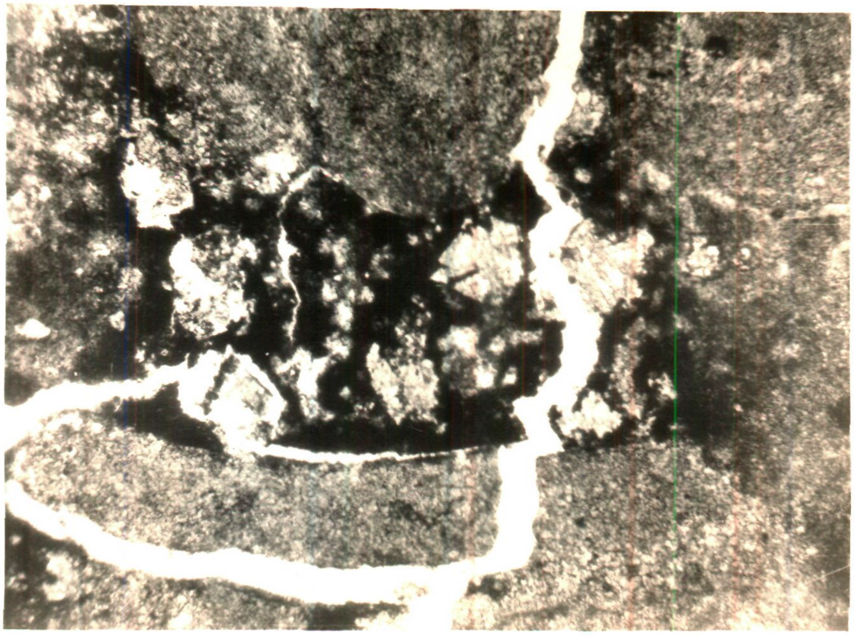

Figure 15. Dolomite occurring in patches. The dolomite crystals are highly ferruginous and showing dark margins.

Figure 16. Mutually interfering highly ferruginous dolomite rhombohedra.

dolomitization, dolomite occurs in the form of a ring around the allochem (Fig. 18). As dolomitization proceeds, the allochems are gradually replaced.

The rocks were originally deposited as pelleted mudstone which as a result of extensive dolomitization and recrystallization has lost much of its original texture. However, micritic inclusions and dolomite rhombs and preferential dolomitization of pellets suggest that pellets and micrite were the main original constituents of the rocks. Presence of pelleted mud and extensive dolomitization suggest an intertidal environment of deposition of the rocks.

In the upper part of the Joyan Member, dolomite forms an important constituents of the rocks and averages 21 percent. The rocks of the Joyan Member are mainly pelemicrites with abundant terrigenous admixture which average 42 percent. Pelleted micrite forms on average 24 percent, and sparry calcite 9 percent. Minor constituents include intraclasts, bioclasts and superficial ooids.

Dolomite is common in the terrigenous pelmicrites and various stages of transition from calcite micrite to dolomite are seen in different thin sections.

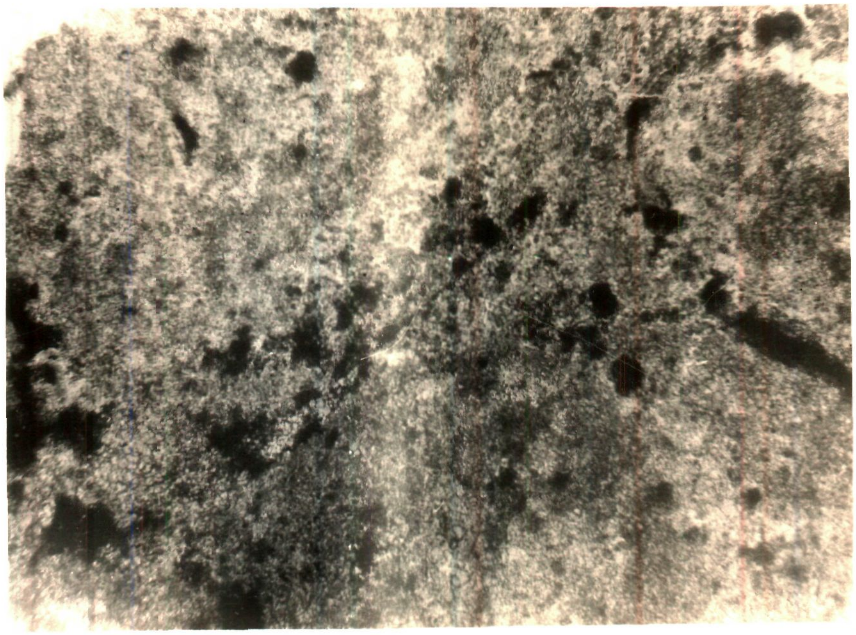

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Figure 17. Single floating crystals of highly ferruginous dolomites.

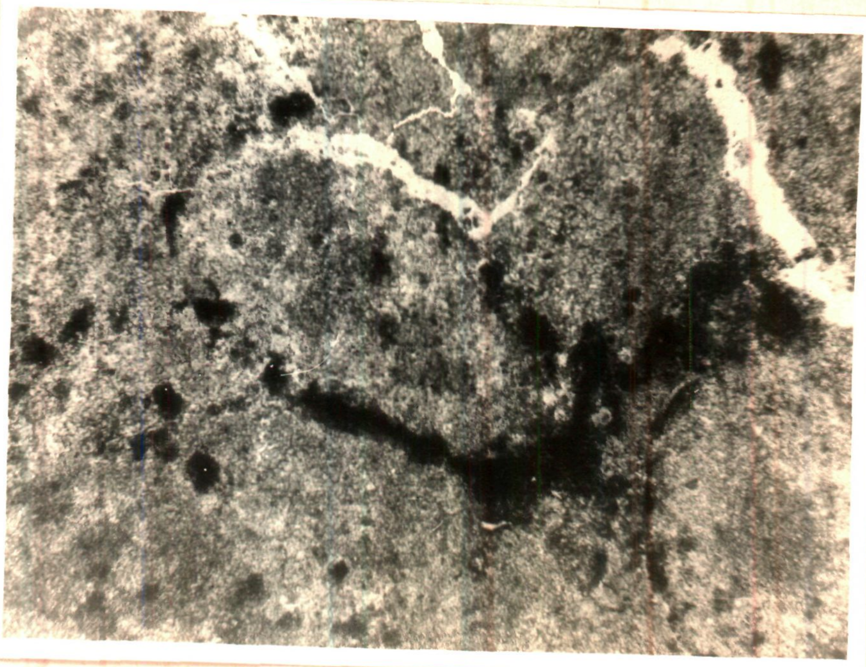

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Figure 18. Dolomite occurring in the form of ring around an allochem.

Aphanocrystalline to very finely crystalline dolomite crystals occur isolated or in clusters in clacite micrite. With increasing dolomite content the dolomite crystal form a continuous framework with small remnant patches of calcite in micrite. With increasing dolomitization, dolomite crystals increase in size and become medium crystalline. The dolomitized patches show increase in crystal size outward from the central portion. The central portion of patches consist of aphanocrystalline to very finely crystalline dolomite crystals in which rhombic shape is not discernible. Towards the margin of the patches dolomites crystal are medium crystalline and display rhombic outlines. Large dolomite crystals show zoning and central part of such crystal is generally calcitic. Dolomite is intimately associated with iron oxide and therefore dolomitized patches appear buff or brown coloured.

Dolomitization appears to be selective as certain depositional carbonate constituents were more readily dolomitized than others. The order of preferential replacement by dolomite is micrite, bioclasts and intraclasts. Dolomite is very finely crystalline to medium crystalline occuring in layers which conform to the primary sedimentry layering. The sediment contains algal rich layers which having excess of magnesium (Gebelein and Hoffman 1972), might have contributed to dolomitization. Dolomite is formed by replacement of the surrounding calcium carbonate matrix and therefore, the dolomitization process is secondary but controlled by primary organic rich layers, explaining its selective distribution (Gebelein and Hoffman 1973).

The dolomitized pelemicrites resemble the typical Loferite sediment of (Fischer 1964) and many ancient intertidal deposits (Goldhammer and Elmore 1984). The terrigenous pelemicrites resemble the modern pelleted tidal flat sediments described from the Andros Island, Bahamas (Shinn et al. 1969). The irregular and discontinuous dark coloured organic rich algal laminations seen in the rocks are associated with fenestral fabrics and irregular vugs resulting from desiccation.

ORIGIN OF DOLOMITE

Formation of dolomite/dolostone has been explained by several different processes which include direct precipitation, recycling, penecontemporaneous replacement, refluxion of hypersaline brines, and epigenetic processes (Friedman and Sanders, 1967; Bathurst, 1971).

Dolomite of Jaisalmer Limestone can not be ascribed to recycling or epigenetic processes. There is no petrographic evidence suggesting the presence of recycled fragments of dolostones and abraded single dolomite crystals which are characteristic of recycled dolostones. Epigenetic formation of dolomite is ruled out because localisation of dolomitization along post-lithification structures, a characteristic feature of epigenetic dolomite, was not observed in the Jaisalmer Limestone.

The dolomite under study did not form by primary precipitation, in view of the fact that primary dolomite, as observed in modern environments, is precipitated as dolomicrite. The crystal size of dolomite in the Jaisalmer Limestone is commonly much larger than the micrite size and hence it can not be designated as dolomicrite. There are clear petrographic evidences indicating replacement origin of dolomite. These evidences include (1) inclusions of micrite within the dolomite crystals, (2) zoning of the dolomite crystals, (3) floating single dolomite crystals surrounded by micrite, and (4) presence of relict structures (Friedman and Sanders 1967).

The origin of dolomite under study has also to be considered in the light of intertidal depositional environment interpreted for the rocks. In tidal flat environment processes of capillary concentration, flood recharge and evaporation pumping are characteristic which lead to dolomitization.

In this mechanism the dynamic saline water mass is inferred to be responsible for dolomitization. Here simple capillary concentration by evaporation accompanied by the precipitation of gypsum and subsequent increase in the Mg : Ca ratio of the residual fluid is the potential source for the dolomitization. Recharge of the system may occur by flood recharge. Evaporative pumping is a mechanism for recharge of a marine or hypersaline brine wedge below the tidal flat surface as a result of the vertical movement of the fresh water lens below the tidal flat surface. Movement of this water lens is controlled by evaporation at the surface of the tidal flat.

The common larger size of the dolomite crystals in the Jaisalmer Formation and the complex prominent zoning of many crystals also suggest that dolomite formation may have started early in the burial history thus explaining the petrographic relationship, and these partially dolomitized sediments then acted as a guide for the latter dolomite precipitation, which enlarged the crystals by replacement and concentration to their present size.

The mechanism which best explains the dolomite type of Jaisalmer Limestone is initial formation during shallow burial, probably within a few metres of the sediment water interface, driven by the bacterial oxidation of organic matter. The model popularized by such workers as Irvin et al. (1977), Arthur (1983), Claypool (1984) and Burns (1985) is especially relevant. Calcium and carbon are probably supplied by the dissolution of calcium carbonate and additional carbon may be derived from oxidation of organic matter (Burns, 1985).

Since the dolomite was initially formed during shallow burial diagenesis, probably within a few metres or several tens of metres from the sediment water face, it may be referred to as 'Early' dolimite.

CHAPTER - VI

NEOMORPHISM AND NEOMORPHIC SPAR

INTRODUCTION

The term neomorphism was proposed by Folk (1965). It embraces "all transformations between one mineral and itself or a polymorph... whether the new crystals are larger or smaller or simply differ in shape from the previous ones. It does not include simple pore-space filling; older crystals must have gradually been consumed and their place simultaneously occupied by new crystals of the same mineral or a polymorph" (Folk 1965).

Neomorphism involves three kinds of insitu processes which include polymorphic transformations, recrystallization and aggrading neomorphism.

Polymorphic transformations termed "inversion" by Folk (1965) include wet, in situ transformation of aragonite to calcite which is a common process in carbonate diagenesis. Wet recrystallization is probably of importance in carbonate diagenesis only in the later stages of aggrading neomorphism where calcite crystals are growing at the expense of other calcite crystals.

The most striking visible diagenetic change that takes place in the evolution of a limestone is the increase in the content of sparry calcite which is secondary spar formed by replacement of pre-existing micrite. This process whereby finer crystal mosaics are replaced by coarser crystal mosaics of the same mineral or its polymorph is termed 'aggrading neomorphism' (Folk 1965, Bathurst 1967). It includes the familiar diagenetic alteration of micrite to sparry calcite.

Aggrading neomorphism yields a sparry calcite that is always difficult to distinguish from sparry calcite of cement. Careful petrographic study is required for differentiating between neomorphic spar and cement spar. In the case of samples of Jaisalmer Limestone, neomorphic spar was differentiated from sparry calcite cement on the basis of criteria given by Bathurst (1967). The petrographic work of Schlanger (1963) on Cainozoic carbonate sediments demonstrated that the growth of neomorphic spar begins in the partly unconsolidated sediment. It is apparent, therefore, that the process is not solely a matter of recrystallization, but involves also, in its, earlier stages, the wet transformation of aragonite to calcite and some passive dissolution and precipitation.. Thus it has a somewhat broader meaning than Folk's "aggrading neomorphism" as strictly defined but follows it in spirit (Bathurst, 1967).

Despite the widespread occurance of neomorphic spar its actual growth has not been observed either in the field or in the laboratory. We are faced with the familiar geological task of imagining hypothetical processes.

NEOMORPHIC SPAR IN JAISALMER LIMESTONE

The neomorphic spar of the Jaisalmer Limestone was studied under thin sections. As already mentioned, terrigenous micrite rocks of the Hamira Member are extensively dolomitized and recrystallised, containing about 22 percent neomorphic spar. In addition to this rock, neomorphic spar occurs mainly in the middle part of the Fort and Kuldhar Members of the Jaisalmer Limestone.

The nodular bedded limestone forming the middle part of the Fort Member contains 25 percent neomorphic spar. The other constituents of the rock are abundant pellts (18-62 percent), bioclasts (10-28 percent) terrigenous admixture (2 percent) ooids and intraclasts (1 percent). Micrite matrix fills up interparticle pore spaces, shell cavities and vugs. The micrite matrix and allochems are mostly altered to neomorphic spar. Due to extensive diagenetic alteration micrite and allochem are now largely represented by neomorphic spar (Fig. 19).

Diagenetic alteration to neomorphic spar is also abundant in the bioclastic packstone occuring in the middle part of the Kuldhar Member. In this rock, neomorphic spar constitutes 23 percent. Bioclasts are abundant forming about 62 percent and the other constituents are pleoids, terrigenous admixture and traces of ooids and intraclasts. The original micrite occuring in the intergranular spaces of the packstone as well as the grains have been diagenetically altered to neomorphic spar. Brachiopod fragments show resistance to alteration and their internal structure is still preserved (Fig. 20). In highly neomorphosed rocks, allochems appear as relict structures and are recognisible only by their outlines (Fig. 21).

DIFFERENTIATION BETWEEN NEOMORPHIC SPAR AND CEMENT

In many limestones the distinction between cement and neomorphic spar is straight forward because all the

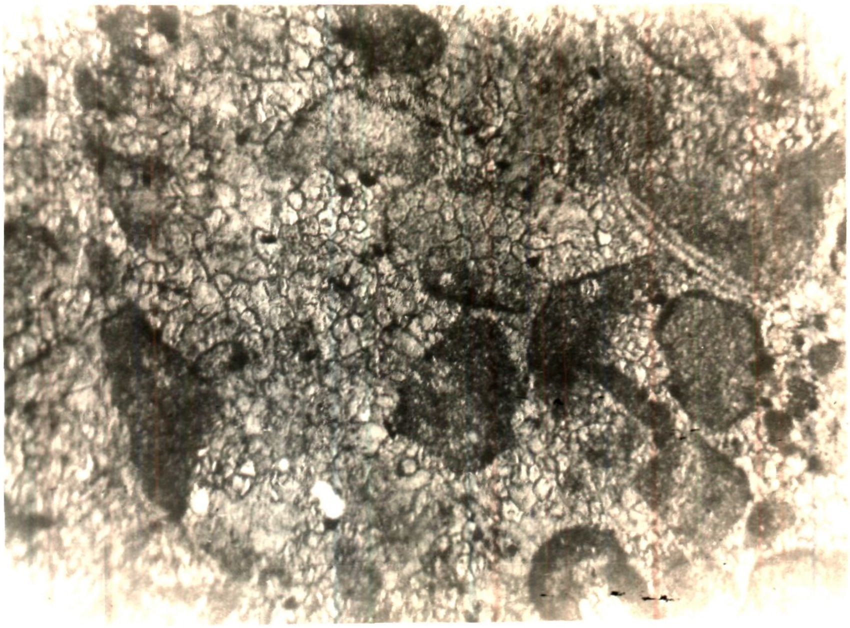

Figure 19. Partial replacement of allochems and micrite by neomorphic spar.

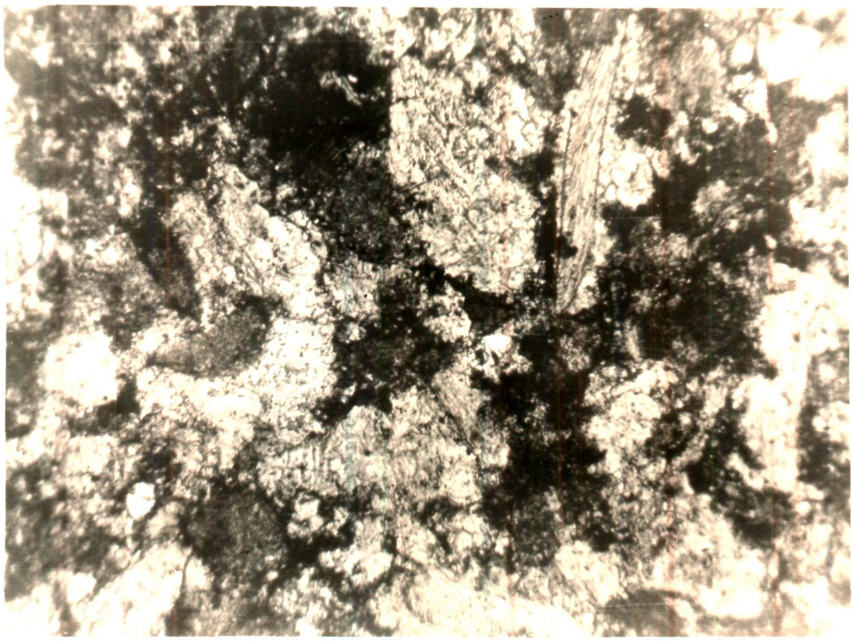

Figure 20. An advanced stage of neomorphism showing highly recrysstallized bioclast and a resistant brachiopod fragment.

criteria point in one direction. In difficult cases it is important to employ as many criteria as possible. Neomorphic spar in the Jaisalmer Limestone has been differentiated from sparry calcite cement using the following criteria given by Bathurst (1967).

1. The size range of crystals of the neomorphic spar in the studied samples is 0.04 mm to 0.16 mm and matches that of the general size range of neomorphic spar (0.04 mm to 0.40 mm).

2. The contact between unaltered micron-sized material (micrite) and neomorphic spar is generally gradual inthe studied samples. The intermingling of fine and coarse crystals makes it impossible to draw a line of separation between micrite and neomorphic spar. The two can be clearly demarcated in case of cements.

3. Crystal size in the neomorphic spar of the studied samples varies irregularly from place to place. In this it differs from the regular vectorial change of crystal size in cements. In a granular cement mosaic filling up an interparticle pore space, crystal size of spar increase towards the centre of the cavity filling.

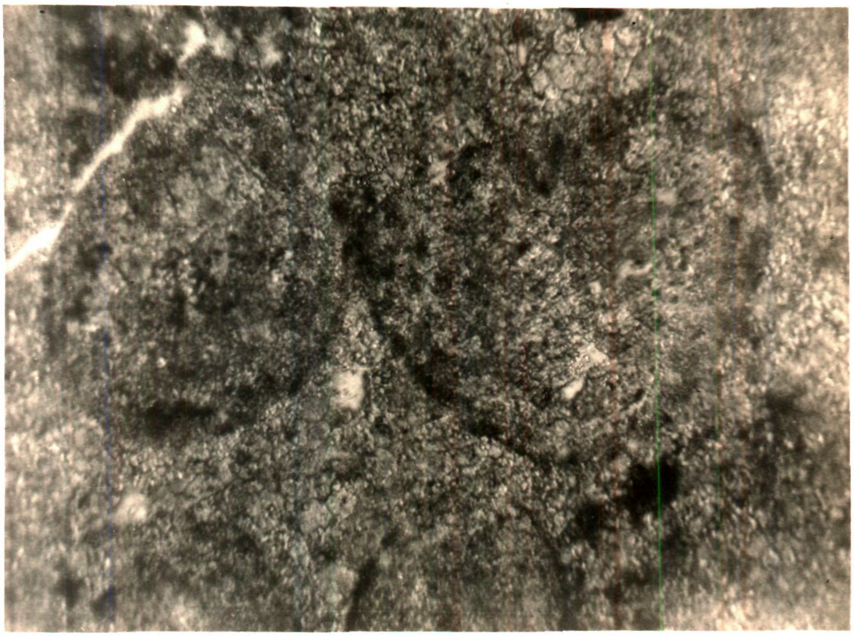

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Figure 21. Advance stage of neomorphism showing allochems a relict structures.

4. The intercrystalline boundaries in the neomorphic spar vary generally from curved to irregular. The plane boundaries so typical of cement are uncommon.

5. Folating relics of original textural constituents, for example, patches of micron-sized material surrounded by spar are noted in the Jaisalmer Limestone. The recognition of floating grains is particularly difficult because grain shapes are so variable. However, the disrupted framework of rock comprising floating grains in matrix of sparry calcite is difficult to explain. The original rock, that is wackestone contained abundant micrite matrix. Diagenetic alteration of micrite matrix resulted in neomorphic spar but some remnant patches of unaltered micrite have been left behind, appearing as relict structure. It may therefore be assumed that the sparry matrix has replaced an earlier mechanically deposited micrite matrix.

6. Bioclasts and shells initially composed of micron-sized aragonite or high-magnesian calcite are partially replaced by neomorphic sparry calcite. Their original shell structure is lost. The crystals size of the replaced spar vary in diameter from 0.04 mm to 0.12 mm. The intercrystalline boundaries are generally wavy.

CHAPTER - VII

SUMMARY AND CONCLUSION

Jaisalmer Basin regarded as a potential hydrocarbon basin comprises a thick sedimentary sequence, of which the Jaisalmer Formation is one of the best exposed Mesozoic formations. The present study based mainly on thin section petrography deals with the textural characteristics and diagenetic aspects of the Jaisalmer Limestone.

The textural study was carried out on grainstones of the Jaisalmer Limestone. Size, roundness and shape of bioclasts were estimated.

Mean size (M_z) of the grainstones range from 0.10 to 2.40 Ø. The wide range in the mean size suggest that during deposition of the sediments energy condition were not uniform in the basin.

Standard deviation (σ_I) range from 0.16 to 1.23 Out of 12 samples, six samples are moderately sorted, two samples are moderately well sorted, one sample is very well sorted and three samples are poorly sorted. The moderately sorted to moderately well sorted nature of most samples indicate currents of moderate competency and persistency.

Skewness of the samples range from -0.6 to 0.50. Most samples are either strongly fine skewed (six samples) or strongly coarse skewed (four samples). The remaining two samples are fine skewed. Kurtosis (K_G) range from 0.58 to 1.4. Seven samples are leptokurtic, four samples are platykurtic and one is mesokurtic. The skewness of the samples also suggest fluctuating currents; fine skewed samples indicating lack of winnowing action of waves and currents (low energy environment), whereas coarse skewed samples evidence strong and persistence currents.

Most bioclasts in the grainstones are fairly well rounded to very well rounded. They show biomodal sphericity as a result of differences in original shape of particles; brachiopod fragments show low sphericity whereas pelleoids show high sphericity .

The Jaisalmer grainstones were subjected to mechanical compaction. Grain breckage was important mechanical compaction process as compared to the plastic deformation and re-orientation of the grains. Compactional breakage of brachiopod fragments is observed as across shell fractures. Minor plastic deformation was observed in some samples which show skeletal fragments bent against pelleoid grains. Microsutured brachiopod fragments and microstylolites indicates minor dissolution and moderate chemical compaction.

Three types of calcite cements were recognised in the Jaisalmer Limestones. The cements comprise fibrous cement (2-3%), granular cement (10-15%), and syntaxial rim cement (1-3%). The fibrous calcite cement represents a very early post-depositional submarine cement which was precipitated while pore waters were still in close communication with normal marine water. In all probability cementation occurred in the active marine phreatic zone. A change from marine phreatic to freshwater phreatic environment brought about precipitation of sparry calcite cement occurring in the form of granular mosaics. The syntaxial rim cements forming overgrowths echinoderm fragments was also formed in the fresh marine phreatic environment to fresh water phreatic environment was perhaps a result of regressive phase accompanied by a fall in sea level.

Dolomite mainly occurs in the lower two members of the Jaisalmer Limestone i.e., Hamira Member and Joyan Member. These rocks contain upto 45% dolomite which occurs in patches as well as single floating crystals. The dolomite crystals are highly ferruginous. Dolomitization has affected mainly pelleoids but bioclasts have also been replaced.

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There are clear petrographic evidences indicating replacement origin of dolomites. The dolomitized rocks were originally deposited as pellet mudstones which as a result of extensive dolomitization and re-crystalization have lost much of their original texture. They resemble the modern pelleted tidal flat sediments and many ancient intertidal deposits. The dolomite of the Jaisalmer Limestone was formed in the tidal flat environement by processes of capillary concentration, flood recharge and evaporation pumping.

Neomorphic spar occurs mainly in the Hamira Member and in the middle part of the Fort and Kuldhar Members of the Jaisalmer Limestone. It forms up to 25% in these rocks. They are mostly packstones comprising allochems and micrite matrix which are now largely represented by neomorphic spar due to extensive diagenetic alteration. Brachiopod fragments areresistant to neomorphism and their internal structure is mostly preserved. In highly neomorphosed rocks, allochems appear as relict structures and are recognisable only by their outlines. Distinction between neomorphic spar and cement spar is generally difficult, but in the case of the studied samples the two types of sparry calcite have been carefully distinguished on the basis of criteria, such as size range of crystals, size distribution of crystals, contact between micrite and sparrycalcite, intercrystalline boundaries and floating relics of original textural constituents.

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APPENDIX - I :Grain size frequency distribution (number percent) of Jaisalmer Limestone.

Samlpe No.	1.0	-0.5	0.0	.05	-1,0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5
17	-	-	-	-	-	5.6	28,3	18.8	15.7	10.6	11.9	7.5	1.2	-
28	-	-	1.0	7.5	-2.8	34.5	21.0	7.0	1.0	-	-	-	-	-
29	2.6	3.5	5.2	4.3	7.0	13.1	26.3	13.1	8.9	5.2	6.2	4.4	-	-
30	-	-	-	-	0.5	1.0	11.9	29.7	28.7	12.9	9.4	3.0	3.0	-
32	-	-	-	-	-	10.5	23.6	28.9	21.0	13.1	2.6	-	-	-
34	-	0.5	1.0	8.6	29.0	25.7	12.4	6.7	4.8	5.2	4.3	1.9	-	-
35	-	-	-	4.4	2.6	8.0	20.5	35.7	23.2	5.3	-	-	-	-
36	-	-	-	2.3	3.3	21.2	16.5	30.6	16.5	9.4	-	-	-	-
37	-	-	-	1.4	2.8	1.8	10.4	22.7	32.7	16.5	9.4	1.8	-	-
38	-	-	-	-	-	9.4	25.3	21.4	19.3	15.0	6.4	2.1	0.8	-
39	-	-	-	.8	2.9	5.1	19.1	24.2	21.2	17.0	8.0	1.2	-	-
40	-	-	-	-	7.9	11.7	11.3	22.7	15.2	9.6	13.1	5.2	3.0	-